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THE SIGNIFICANCE OF COTTON FIBER PROPERTIES WITH RESPECT TO UTILIZATION

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INTRODUCTION

Much is being thought, spoken, and written these days about cotton utilization, about new and extended uses for cotton, and about cotton improvement programs. For the most part, the advancements and proposals have to do with the future; that is, what might be done, what should be done, and what is proposed to be done. This, of course, is all well and good.

At this time, however, it seems desirable for me to discuss cotton fiber properties as regards their significance with respect to utilization, and to point out some accomplishments from the cotton quality and standardization researches of the Agricultural Marketing Service (formerly of the Bureau of Agricultural Economics) that have a direct or indirect bearing on cotton utilization and on cotton utilization studies. Such considerations are appropriate at any time but more especially so on a program of this type and during a Cotton Congress of this kind, when everybody is endeavoring to test the accuracy of his "cotton" thinking and the soundness of the cotton utilization, marketing, standardization, breeding, production, and improvement programs. Unless we take comprehensive stock now and frequently hereafter of all points of view and of the principal new developments, without bias and prejudice, we cannot achieve with a minimum of time, effort, and expense, maximum benefits for American cotton, for Southern agriculture, and for individual cotton farmers.

COTTON STANDARDIZATION WORK AND RESEARCHES

The American cotton crop embraces an almost unbelievably wide range of qualities and fiber properties. Efficient marketing and utilization, therefore, necessitate proper identification, selection, and description of like qualities. In cotton breeding and ginning, and in the development and improvement of marketing methods, moreover, much emphasis is being given to quality. But to measure cotton quality, various standards, specifications, and techniques are required, by means of which elements in quality may be compared and evaluated.

Under authority as provided by five special acts of legislation, the Agricultural Marketing Service is charged with the responsibility of cotton

standardization and classification work of the U. S. Department of Agriculture. To handle this responsibility naturally requires a large number of very closely related and coordinated functions and activities.

For the purpose of supporting, reinforcing, and improving this cotton regulatory and service work, the Agricultural Marketing Service has found it necessary to carry on cotton quality, standardization, and marketing researches. The technical phases consist of extensive fiber, ginning, packaging, and spinning studies which are so closely related and coordinated as to constitute one unified program. The researches and the service work, moreover, are especially designed and conducted so as to supplement each other in a very intimate and mutually helpful way.

The research program involves a group of technical facilities in Washington and in the field. The number of laboratories and people employed for this work are about equally divided between the two. A large part of the work is done in the southern cotton States through formal or informal cooperation with various agricultural and mechanical colleges, agricultural and engineering experiment stations, and with private firms and agencies, growers, ginners, classers, shippers, warehousemen, compressmen, and merchants. Contacts also are maintained with various branches of the textile industry, including, among others, tire cord and rubber firms, thread manufacturers, and textile schools.

Those parts of the fiber and spinning work which relate to cotton breeding, production, and improvement programs are conducted in close cooperation with the Bureau of Plant Industry, and the studies are confined to case-historied samples. Those parts of the investigations which are associated with cotton ginning and packaging are handled jointly with the Bureau of Agricultural Chemistry and Engineering. The spinning work is done in laboratories at College Station, Tex., and at Clemson, S. C., through cooperation with the Texas A. & M. College and the Clemson Agricultural College, respectively. The ginning and packaging work is carried on at the U. S. Cotton Ginning Laboratory at Stoneville, Miss.

The nature and scope of the cotton quality and standardization research program of the Agricultural Marketing Service and of the progress that is being made were discussed in considerable detail last fall before a meeting of the American Agronomy Society. In view of the fact that copies of that presentation are available for distribution and that the ginning phases have been considered on a previous program of this Cotton Congress, the standardization and ginning aspects, as such, will not be considered in this presentation.

CERTAIN BACKGROUND CONSIDERATIONS IN REFERENCE TO COTTON QUALITY

In connection with cotton standardization and utilization problems and studies, there are certain points and relationships which generally are not realized by the average layman nor by every student of cotton. Let me illustrate a few of the matters to which I refer. I think that it is of particular interest to note the following: (1) That, insofar as the unit of manufactured product is concerned, the cotton textile industry hangs by a single thread;

(2) that the fundamental unit of that thread, as well as of the entire cotton enterprise from the producer to the consumer--insofar as raw cotton is concerned--is the single fiber; and (3) that, insofar as fiber properties and qualities are concerned, the law of averages saves the cotton enterprise and the textile industry.

But, how far from simple the problems of cotton utilization, character, standardization, and classification really are can be fully appreciated only when it is realized that a bale of raw cotton is not a homogeneous material in the same sense as a keg of nails. Quite the contrary, cotton is an aggregate of individual fibers, and each fiber is a separate entity in itself. On a basis of our laboratory data, we calculate that there are around 90 million fibers in a pound of cotton and around 45,000,000,000 in a 500-pound net bale. Or, expressed in another way; the number of fibers in a pound of cotton equals roughly three-fourths of the population of the United States and the number of fibers in a 500-pound bale equals roughly 345 times our population.

Moreover, great variability exists not only between the different fibers but within the individual fibers themselves. Each of these fibers is a hollow cell formed as a tube, varying in length from 1/16th of an inch or less, to more than 2 inches; with walls collapsed at maturity in greater or less degree; and with lateral convolutions varying from almost none to 500 or more. The shapes and areas of the cross section of the fiber also are usually variable throughout its length.

Furthermore, the fact that the fiber length may be as much as 4,000 or more times its width taxes the best of microscopic technique. To illustrate, if a 1-inch cotton fiber with about average cross-sectional features is magnified so that its width is 1 inch, it will assume a length of about 100 feet. And, if a more or less average 2-inch sea-island fiber is magnified so that its width is 1 inch, it will assume a length of about 400 feet. Fantastic as these figures may seem, they nevertheless illustrate the extreme and unusual type of ratios with which we have to grapple in dealing with problems in our cotton work.

RANGES IN VARIOUS COTTON FIBER PROPERTIES

More specifically, based on thousands of tests made in our laboratories on as many samples and millions of fibers, a preliminary analysis of our data reveals relatively wide ranges in all of the fiber properties measured and enormous ranges in most of them. The ranges of values found are shown by the data given in table 1.

By referring to the figures cited, it will be seen, for example:

That the over-all area of cross section of cotton fibers varies from as low as 26 square microns to as high as 1164 square microns, or a range based on the minimum of 4,377%.

That the range of wall thickness in cross section varies from as little as 0.35 microns to as high as 15.5 microns, or a range of 4,328%.

Table 1.--Range of values of cotton fiber properties

Fiber property	Maximum value	Minimum value	Percentage range based on minimum
Area of cross section, sq. microns	1164	26	4377
Wall thickness, microns	15.50	0.35	4328
Lumen width, microns	12.00	0.35	3328
Major lumen axis, microns	40.00	0.50	7900
(The cross-sectional shapes of fibers vary almost as much as the size and wall thickness)	-----	----	----
Thin-walled fibers, percent	77	6	1183
Staple length, inches	2	½	300
Coef. length var., percent	65	18	261
40 percent angle, degrees	45	23	96
Fluidity of cellulose, rhes	50	2	2400
Copper number, units	1.5	0.2	650
Alkali solubility, percent	7	2	250
Wax content, percent	10.0	0.5	1900
(Color ranges from the most delicate of creamy whites to the deepest sort of yellow stain)	-----	----	----
Chroma, units	3.20	0.6	433
Chandler bundle strength, 1000 lbs./sq. in.	120	40*	200

* As low as zero in some deteriorated cottons, the fiber bundles not being strong enough to support even the weight of the jaws of the testing machine

That lumen width varies at least from 0.35 to 12 microns, or 3,328%.

That the major axis of the lumen varies from as low as 0.5 microns to as much as 40 microns, or 7,900%.

That the cross-sectional shapes of cotton fibers vary almost as much as the size and wall thickness.

That the proportion of thin-walled fibers varies from as low as 6% to as high as 77%, or a range of 1,183%.

That the soundness of the cellulose varies greatly as indicated by fluidities ranging from 2 to 50 rhes (2,400%), copper number from 0.2 to 1.5 (650%), and alkali solubility from 2 to 7 percent (250%).

That the wax content varies from 0.5 to 10.0, or a range of 1,900%.

That the color ranges from the most delicate of creamy whites to the deepest sort of yellow stain, chroma units being as low as 0.6 and as high as 3.20, or a range of 433%.

That the fiber bundle strength varies from 40,000 lbs. per square inch to as high as 120,000 lbs. per square inch, or a range of 200%. (Strength values have been found to be as low as zero in some deteriorated cottons, the fiber bundles not being strong enough to support even the weight of the jaws of the testing machine.)

A SUGGESTED METHOD OF APPROACH FOR COTTON UTILIZATION STUDIES

Differences in the properties of different varieties and species of cotton are influenced, of course, by environmental conditions during growth and development of the fibers, by the length of time and climatic conditions during exposure of the fibers in the field after the bolls open, and by the conditions during and methods of harvesting, ginning, storage, and subsequent handling. In view of the fact that our results show that there are tremendous, almost unbelievable, variances in the properties of cotton the question of selecting it with due regard to suitable properties for promoting each old use, for developing each new use, and for conducting special utilization studies would seem to be of very great importance. In addition, the material currently available in various Federal, State, and private breeding and other experimental plots, as well as that which likely could be made available by those sources, if desired, would seem to offer great possibilities as a starting point for certain types of cotton utilization studies.

Obviously, such fiber properties and variabilities in raw cotton as mentioned, plus modification by physical processes and chemical treatments during the course of manufacture, constitute the fundamental basis for cotton utilization. That is, causes for the wide ranges in strength, stretch, elasticity, resistance to flexure, fatigue, abrasion, fading, and laundering which cotton yarns and fabrics show, all have their roots deep in the inherent properties of the individual fibers and various combinations of them. Likewise, causes for the wide ranges in dyeing and finishing, shrinkage and swelling, actual service performance, and total life-wear that products manufactured from cotton show, all have their roots in the inherent fiber properties of the raw cotton, plus effects of design, construction, and finish of product and of any deterioration that may have been induced by physical, chemical, or microbiological agencies. The role and significance of cotton fiber properties with respect to utilization, therefore, should and must not be overlooked or underestimated.

The different uses to which the manufactured products are to be put, of course, require different combinations of fiber properties. That is, a cotton which is best for a tire cord or a balloon fabric because of the high strength of its yarns, cords, or fabrics, may not be desirable for terry towelling, which requires a fluffy, resilient yarn. However, the exact combination of fiber properties that would best serve each and every major and

specialized use of cotton is not definitely known. Furthermore, exactly how the various fiber properties operate in yarns and fabrics under the stresses and strains of ordinary wear and tear, or even under laboratory test conditions, and how the many forces interplay through individual fibers and groups of fibers in yarns and fabrics are not known with the precision and completeness that they should be known for purposes of cotton utilization, standardization, breeding, and production. Baffling relationships, interrelationships, and complexities seemingly abound on every hand. As a result, there is today almost no end to the number of important questions that cannot be answered properly.

Therefore, when we know better than we now know just what properties of cotton yarns and fabrics the different major and specialized uses actually require; just what their minimum and maximum values are; just what is the nature and degree to which these, in turn, are influenced by different fiber properties and combinations of them; and just how and to what extent these, in turn, are influenced by heredity, environment and handling, we shall be much farther along than we are today in our "cotton" thinking. Also, we shall be much farther along on our march to develop greater utilization and outlets for American cotton; to bring forth superior varieties of cotton that will better meet ordinary and special-use requirements; and to supply the markets of the world with American cotton that possesses the greatest possible strength, beauty, and appeal to spinners and other manufacturers.

This is the challenge! In order to meet it most effectively and to take the fullest advantage of the opportunity, we must pull together 100 percent in both letter and spirit. Even this concerted effort is none too much for this enormous task and responsibility.

And that brings me to this thought: Technical research laboratories can be built most any time and at most any place, and testing machines can be purchased world without end. All that is required to do these things is money. But, while these items are essential, the most important, and the scarcest, ingredients in research--as well as in most walks of professional life--are brain power, ideas, leadership, and inspiration. All of us who have had any appreciable responsibility in connection with directing research programs know, by sad observation and experience, that leadership with its attendant creative ability, imagination, and inspiration cannot be purchased in the open market. A person either has the qualifications for leadership and for outstanding accomplishments, or he does not. Moreover, to be successful, the leaders, the supervisors and the key workers must not only have accumulated knowledge and technique, and possess the ability to grow in these respects, but they almost must have a proper mental attitude, common sense, stamina of character, and a sense of humor.

So, regardless of how many cotton utilization, spinning, and fiber laboratories are built, how much testing equipment is purchased, how many appointments are made to the staff, how much technical training the personnel has, and how many cooperative agreements are executed, the accomplishments will and can be no greater than the degree to which there is wholesome and effective team work and cooperative effort. And, the team work and cooperative

effort. And, the team work and cooperative effort will and can be no greater than the individual and group attitudes of all persons concerned, with respect to each other and to their respective responsibilities.

SOME ACCOMPLISHMENTS OF INTEREST TO COTTON UTILIZATION AND UTILIZATION STUDIES

In connection with the cotton quality and standardization researches of the Agricultural Marketing Service, a number of achievements in the way of technique, apparatus, and knowledge may be mentioned that should be of value to cotton utilization and to cotton utilization studies. The more pertinent of such developments are described in the following sections.

Development of Instruments and Methodology for Staple Length and Grade Factors

One of the first and most important considerations in dealing with problems of cotton quality standardization in relation to breeding and production, improvement programs, marketing, and utilization is the establishment of appropriate quality bench marks and the provision of practical ways and means for comparing and evaluating elements of cotton quality. In attempting to establish staple length standards on a scientific basis, the need immediately arises for an instrument and method whereby the length of fibers in cotton lint and in staple standards can be precisely measured and expressed.

After examination of such scientific instruments as were available it was found that none were well adapted for this purpose. We therefore set to work and developed an instrument which would accurately and conveniently separate the fibers according to their length and in turn worked out a standard method whereby the length distribution of samples of cotton may be accurately recorded and expressed in statistically significant figures. A public patent was obtained upon this instrument so that it could be made available to the public without payment of royalties. This instrument has been used extensively in our laboratories and its usefulness and practicability have been thoroughly established. A method based on its use is described in the Handbook on Textile Materials, as published by the American Society for Testing Materials.

A photoelectric fiber length meter is now under study and refinement for automatically recording the length distribution of any sample of cotton fibers. Preliminary observations are already being made. If such a development can be brought to a stage of practical perfection much will be done to to remove the personal equation from fiber-length measurement. To this end, it should be pointed out that it is comparatively easy for one to concoct a device to measure something about a fiber, yarn, or fabric.

The most difficult and important thing of all, however, is to determine what the results mean, if anything, in terms of practical significance. This, of course, requires a considerable statistical background of a biological and technical nature which generally requires much time, labor, and patience but which is needed, if the relative merits and demerits of any such new development

can be established. To illustrate, we are finding that the apparent fiber length, as determined by our photoelectric meter, is influenced not only by the nature and manipulation of the same, as would be expected, but also appreciably by the color and fineness of the fibers and by the percentage of thin-walled fibers.

In connection with the grade of cotton lint, color is one of the more important factors. Color, however, consists of several elements which cannot be very readily compared simultaneously with the eye. Especially, is such comparison impractical under varying light conditions and over extended periods of time. Accordingly, one of the first problems in the application of scientific methods to the improvement of grade standards was to develop a special instrument by means of which the color of any sample of cotton can be accurately specified in terms of standard colors. This was accomplished through the development of a special disk colorimeter which has also received a public patent.

In this way, the necessity for cotton classers to remember colors is circumvented and the colors of samples of cotton may be precisely compared even though they are not seen by the same person at the same time and place, or even though their examination may be separated by a period of years. The results are expressed in units which are directly comparable with what the cotton classer sees, and thus may be related directly to practical experience. The machine has gone through a series of developments and improvements, which may not yet be considered concluded. Considerable use is being made of the instrument not only in Government classing rooms but in the cotton industry.

One of the factors that interferes with cotton classification, especially decisions with respect to the grade, is the matter of variable quality of light. During the past several years, our laboratories have made a careful study of the light conditions in various classing rooms throughout the Cotton Belt and in Washington. Also, we have made a careful examination of various sources of artificial illumination with a view to selecting the most suitable ones and thus standardizing the quality and intensity of light that may be used in cotton classing rooms in place of natural illumination. Specifications have been worked out for satisfactory artificial daylight installations and small units are being installed for trial in a number of the field classing offices as well as by private concerns. It is expected that improved lighting may greatly facilitate the matter of cotton grading and increase its accuracy.

An automatic cotton grader has been designed and is in advanced stages of construction. This instrument is in the form of a scanning device by means of which a photoelectric cell automatically records the color, leaf, and preparation of any sample of cotton presented to it. Such an instrument as this should be very valuable in eliminating the personal equation in the grading of cotton. Here again, a considerable statistical background of a biological and technical nature is required before the full meaning and practical significance of the recorded data can be ascertained.

Service to the Grade and Staple Standards

One of the more important accomplishments for a number of years now has been more precise copies of the official grade and staple standards for distribution to the public. For the grade boxes, all the key sets are always carefully measured with respect to color. Any appreciable variations between key sets are noted and such sets are re-examined and perhaps adjusted to bring them into proper agreement. Furthermore the Universal Standards for grade were revised in 1935, to become effective in 1936, partly because it was shown by color measurements that the standards were no longer properly adapted to the crop and partly because such measurements showed that the number of physical representations could be reduced quite materially to advantage. The information to show that the grade standards no longer represented the crop was obtained through the collection of many samples from the Cotton Belt and from the markets, extending over a period of several years, and by our color technologists and classers working in the closest possible cooperation with each other.

In a similar way the use of the cotton fiber sorter and the standardized method for the measurement of cotton fiber length have made possible a much more precise copy of the staple standards for distribution to the public than could possibly be accomplished without this service. For some years every bale to be considered for use in preparation of staple types has been carefully sampled and a number of such samples, usually three or more from each bale, have been sorted according to fiber length. Many bales under consideration for the preparation of any staple length type are rejected as a result of such examination. Furthermore, after staple types have been prepared in the one pound cartons and supplied to the trade occasional complaints arise as to the correctness of the assigned staple length. Such types are re-examined with great care to determine the accuracy of the copy.

Still further valuable service has been rendered to cotton classing through comparison of the fiber length array obtained by sorting with the staple length assigned by the classer. This has been done on a large number of samples and for many classers. Thus, the nature of the differences of designation by different classers has been revealed in many cases. In addition, the results have shown how the staple length assigned may vary with the condition under which the classing has been done. It has been found that the position in the fiber-length array at which the classer designation may fall may vary greatly, depending upon the appearance of the cotton and perhaps the speed with which the classer is working. Especially, variations in moisture condition of the sample may influence the position at which the classer designation may fall. All these findings have tended to improve the classing service and to give it a precision that it could not have attained without the scientific background.

Development of Methods and Instruments for Character Properties

One of the foremost problems of our technological laboratories almost from the beginning has been that of isolating, measuring, and evaluating those

properties of cotton ordinarily grouped together as "character" properties. These properties must account for the wide discrepancies so often observed by spinners between the strength and other properties of their manufactured products and that which would be expected on the basis of the assigned grade and staple length. There have been years when these differences were most pronounced, as for example, the years 1931 and 1937 as compared with those which immediately preceded and followed them. Work on the character properties has proceeded along the line of such properties as may most logically be expected to affect yarn and fabric quality. No claim is yet made that we have discovered all the properties that may be expected to be influential. Some of them are indeed very difficult to attack because of the tediousness of the methods thus far devised. Still others are extremely vague at present due to lack of theoretical background for their comprehension.

One of the more immediate character properties is that of distribution of fiber length. This is not the length designation or length value that is given to a sample but rather the degree of variation that exists in the length of the fibers that compose the sample, every sample being made up of many different lengths in various proportions. There is a belief among many classers that they can distinguish differences in fiber length distribution, and to a limited extent, this seems to be true. In one test, involving a considerable number of samples that were segregated into groups according to degree of variation of length by a number of cotton classers, it was found that extremely great variability of fiber length could be detected in the majority of cases. Frequently, however, designations of high variation, such as "irregular" and "wasty," were given to samples having length distribution equal to or better than the average for cottons whose length distribution was so good as to be called "uniform" or "normal." The fiber length sorter provides a ready means for the precise measurement of length distribution for scientific purposes, and the relationship of this property to yarn and fabric properties has been rather extensively examined. The need still exists for some rapid means for measuring this property for commercial purposes and it is hoped that a practicable automatic sorter, either of a mechanical or photoelectric type, or a combination of the two, may be the solution to this problem. Progress is being made but the ultimate goal requires travel over a road that is long, difficult, and tedious.

Another property which has been found to be of first importance is that of fiber fineness. This property is one of the more difficult to measure because of the great variability of fineness from fiber to fiber, from staple length to staple length, and from variety to variety of cotton. A method has been developed in our laboratories and adopted by the American Society for Testing Materials for the measurement of this property. Although the method is rather precise and has been employed in all our recent routine work, it is very slow and not well adapted for commercial use. Various attempts have been made to develop more rapid methods for the measurement of fiber fineness including special optical devices, but thus far no entirely satisfactory procedure has been worked out.

One of the more promising techniques for more general practice is that of relatively quickly making cross sections of bundles of cotton fibers

and of photographing them at a magnification of 500 to 1,000 diameters. Very good progress has been made in the development and refinement of this method for special adaption to and use with cotton fibers. The possibilities have not yet been exhausted, but the sections, photographs, measurements, and comparisons can now be made with a speed and ease that heretofore has been unknown. A series of standard photomicrographs of fibers, differing in average cross section progressively from the finest to the coarsest cottons obtainable, has been set up; furthermore these have been varied in each case for degree of wall thickening or development, as based on the three major and predominating fiber types as: linear, concentric, and circular. It is hoped that this technique can be developed eventually to where large numbers of samples can be examined and compared expeditiously with standards, either under the microscope or after photographing, which is something that is so urgently needed in the cotton breeding and improvement programs as well as in the work of cotton standardization and utilization.

Maturity is another character property to which a great deal of attention has been given. For this property, too, a method has been worked out and adopted by the American Society for Testing Materials. This method like that for fineness has been developed to a fairly satisfactory degree of precision, but also like it, the method of test for maturity is very tedious and not suitable for rapid or general commercial application in the accepted sense. Other methods based on polarization colors and anisotropic compensation have been examined. The method based on polarization colors may be used for rough diagnostic purposes but is not suitable for precise differentiation without becoming also tedious and time consuming. The concept of maturity is included in the fiber cross-section classification, already described with respect to fiber fineness, and it is possible that both fiber fineness and fiber maturity can be measured simultaneously for rapid commercial purposes.

Another approach that is possible and has been examined to a limited extent is the application of chemical techniques to evaluate maturity. This is based upon the fact that the chemical composition of cotton fibers varies progressively with the degree of development or thickening of the fiber wall. Although a considerable number of analyses have been carried out,the work in this direction has not yet progressed to a stage where the practicability of this approach can be ascertained.

The strength of cotton fiber is one of the more important character properties. It is self-evident that the strength of the fiber determines or qualifies the strength that may be realized in all products manufactured from the cotton. Although extensive research had been conducted in various laboratories, no satisfactory method for measuring cotton fiber strength in relation to yarn and fabric quality had been developed until the Chandler method was devised and developed in our own laboratories. It then began to be generally realized that the strength of the fiber must be expressed in terms of the area of fiber cross section, if the results are to have significance, since in a yarn it is not the strength per individual fiber but the aggregate strength of all the fibers in the yarn cross section that determines the yarn strength. Whereas methods for measuring fiber strength individually showed no correlation whatever with yarn strength, the Chandler

method has always shown well-defined relationship with yarn strength. The Chandler method has been much improved and highly standardized since the time of the first publication describing the test, and details for the employment of the refined and latest procedure are included in the tentative standards for textile materials of the American Society for Testing Materials.

In this connection, other more or less short-cut methods for testing fiber bundle strength have been studied in our laboratories but none of them have been found to give the degree of accuracy and precision that the improved Chandler bundle method does in the hands of laboratory workers trained and experienced in this highly specialized field of work.

Rather recently, it has been discovered that the structural alinement of the crystalline cellulose in the cotton fiber, with respect to the fiber axis, is a very important element of character. Structural alinement may be measured in a number of ways. Two methods have been studied in our laboratories with the result that an X-ray technique was finally chosen. By means of the X-ray diffraction technique it has been shown that the structural alinement of the successive layers of the cotton fiber varies progressively during growth and that the final mean alinement for a representative sample of fibers is highly dependent upon such factors as variety of cotton, location of growth, and growing season. There seems to be definite evidence that the structural alinement is responsive to the temperature during growth and perhaps also to the moisture conditions of the soil.

Still another element of cotton character is the soundness of the structural substance of the fiber, that is, the cellulose. It is more or less self-evident that if cotton fiber from different sources and conditions of growth varies in chemical composition,--and it does,--that the properties of the fiber may be expected to vary. Studies are under way to determine, if possible, whether cottons vary in their structural soundness at the time the bolls open. It is well known that the structural soundness of the fiber can vary greatly thereafter, because of exposure to light and exposure to the influence of various micro-organisms. For this reason cotton which may have been good and of high quality originally may become deteriorated until it has scarcely any usefulness left. Such deterioration is readily ascertained by the application of cuprammonium fluidity measurements, alkali solubility determinations, and other somewhat similar measures.

Evaluation of the Importance of Cotton Fiber Properties

The various properties of cotton fibers are of no practical interest to utilization, marketing, standardization, breeding, production, and improvement programs in themselves, or when standing alone. Instead, they are of interest and importance to such practical problems only insofar as they have an influence on their manufacturing behavior, the cost of their manufacture, the tested qualities of their manufactured products, the service performance of the products in use, and their life wear. For this reason, the careful search for physical and chemical properties of the fiber that may be of importance and their exact measurement are only one step in the elucidation of the quality of cotton. It is, therefore, necessary to study

these properties with respect to their influence on the strength, stretch, handle, gloss, air and water conductivity, heat conductivity, smoothness, compressibility, durability, and other properties, as well as the cost of the manufactured goods.

The Agricultural Marketing Service receives many letters from persons who assume that some one cotton fiber property, if properly measured, will furnish the complete key to the quality of products they are manufacturing or wish to manufacture. They write to know, not so much whether this is indeed the case, but rather to know which property it is that possesses this magic power. Is it the strength of the fiber, as measured by the Chandler bundle method? Is it fiber fineness? They understand we are applying X-rays to the problem; can spinning value be measured with X-rays? Will cuprammonium fluidity, alkali solubility, or copper number give the spinning value? And so they chase the proverbial gleam.

The truth may as well be stated now as later, and as we continually reply to such inquiries. No single fiber property can be expected to give a complete measure of spinning value. Spinning value is a resultant or embodiment of all of the individual fiber properties. Some of these properties oppose others, some act similarly, and altogether a sort of compromise result is obtained. Theoretically, the spinning value might be thought of as expressed by adding the product of the excess above normal to the proportionate influence of that property for all the fiber properties, which contribute to improve the spinning value, and subtracting the corresponding sum of products of properties and their importance that detract from the spinning value. The result may be seen as the actual spinning value and when compared with some standard, shows whether the spinning value of a cotton is, on the whole, superior or inferior.

Even a spinning test, however, has its limitations in showing the spinning potentialities of a cotton. This is due partly to the fact that when a spinning test is to be made, a large number of choices must be made, more or less arbitrarily, from the infinite number of conditions of temperature, humidity, settings, speeds, drafts, kinds, and numbers of cleaners, twists, roll weights, and the like that might be used on the cotton. Cotton spinners have developed many rule-of-thumb methods, but it may readily be seen that two cottons with different fiber properties probably will not respond the same to a given manufacturing procedure and that always a certain amount of reservation must be made for the fact that the spinning test did not bring out the best that was potentially in the cottons, or compare them under completely optimum conditions.

Having disposed of some of the preliminary considerations and limitations, we are now in a better position to discuss the evaluation of individual fiber properties in terms of spinning behavior and spinning value.

First, let us consider the property of fiber length. Probably little need be said here about it because, although it is one of the more important properties influencing yarn and fabric quality, it is also the best known and best understood of all the fiber properties. It has an important bearing

on yarn strength as well as on the fineness of count that may be spun from a cotton. Tens of thousands of length arrays of cotton samples made in our laboratories have permitted us to show the relation of fiber length to staple length, in a fairly adequate way. The coefficient of correlation between upper quartile length and staple length is well above 0.95,--sometimes as high as 0.99. From a study of the strength of different counts of yarn spun from several hundreds of cottons, over a number of years, and representing a wide range of staple lengths, grades, points of origin, and manufacturing procedures, a formula, often referred to as the A.M.S. formula, has been developed. This expresses the effect on strength that may be expected, on the average, for any count of yarn spun from variations of length of staple within the range of 7/8 to 1-1/4 inches.

Fiber fineness is another factor which has been found to have an important relation to the strength as well as to other properties of yarns. This was first emphasized in our laboratories several years ago when short staple cottons were produced artificially by cutting sea-island and other long fine-fibered cottons into shorter lengths. Fiber length distributions were obtained which were quite comparable with those in naturally occurring short-staple cotton. The fineness of the fiber was the principal difference in these cottons. A most striking result and one which was not originally expected was that the yarns spun from these artificially short cottons was approximately 50 percent greater than that spun from the naturally grown cottons of the same fiber length.

With this lead, a search was made for naturally occurring short fine-fibered cottons. Such a combination was found in the so-called Hopi cotton grown by the Bureau of Plant Industry in some of its experimental plots in Arizona. This cotton, in spite of its very short staple length of only 13/16 inch, gave yarns that were much stronger than those from the average run of upland cottons of comparable staple length; in fact, the yarns from this very short cotton were as strong as those usually obtained from cottons having a staple length of 1-1/8 inches or longer. This very short, but fine-fibered cotton has been crossed with an American variety of longer staple length and better yielding qualities with the result that a hybrid of 1-1/8 inch staple length has been produced which has given yarn as strong as that usually obtainable only with 1-1/2 inch cotton.

Fiber fineness is related not only to the properties of yarn and fabric that may be spun and woven, but to the cost of manufacture. This is a very important consideration and has an important bearing on the choice a manufacturer may make between two sources of supply. In order to attain maximum yarn strength, a fine-fibered cotton requires less twist per inch of yarn than does one that is coarse-fibered. Since the insertion of twist is a sort of bottle neck that determines the speed of spinning, anything that can expedite this process is highly important to spinners.

In this connection, it is believed that breeders in this country can greatly increase the fineness of cotton if only they can have the right kind of tests made at the strategic time and can have the right kind of data on hand for permitting them to select and reject their progenies on this

basis with the degree of reliability and assurance that is needed for the purpose. As it is now, cotton breeders are working very much in the dark and short-handed, not because of any fault of theirs, but because of existing circumstances. Cotton fiber technologists and laboratories, therefore, can render important aid to cotton breeders in their breeding work and, in turn, to cotton production and improvement programs.

Other factors that are receiving special attention in our laboratories from the standpoint of correlation between yarn properties and fiber properties are cell-wall development or "maturity", strength of the fiber, structural alinement of the fiber substance, and composition and deterioration. It has been shown that fiber strength, as measured by the Chandler method, does have an important bearing on the strength of yarn that may be produced, although this is not uniform for all yarn counts. Some preliminary results show that the strength of the fiber is much more important for the strength of coarse yarns than it is for that of fine yarns.

In one particular study determinations were made of the correlation of the Chandler bundle strengths with the strengths of yarn, for groups of 60 to 90 cottons each of the same fiber length. For cottons of 7/8 inch, 15/16 inch, and one-inch staple length, the coefficients of correlation were found to be 0.63, 0.74, and 0.79, respectively. This may be interpreted as indicating that variations in fiber strength account for approximately 40, 55, and 62 percent of the variance in the strength of yarn spun from cottons of these respective length groups. It may be mentioned that no distinction was made for the influence of count upon the correlation coefficient, the weighted 22's yarn strength being used in all of these computations.

In a preliminary examination of the data it has been shown that the strength of the fiber, as well as the strength of the yarn, is dependent to an important degree on the structural alinement of the cellulose of the fiber.

Studies, which should be highly valuable from the standpoint of an evaluation of fiber properties in terms of yarn properties, are being accumulated in connection with the so-called Regional Variety Study. In this case fiber and spinning measurements have already been made on something more than 500 lots of cotton representing 16 outstanding varieties grown at 8 locations across the Cotton Belt, and during 2 successive years. The fiber and yarn analyses remain to be completed for the same locations and varieties for a third growing year. Due to the natural variation in the properties of these cottons, it is anticipated that a careful analysis will lead to a much better understanding of the influence of the different fiber properties on yarn properties.

In connection with the Regional Variety Study just referred to, a special problem came up with the 1937 crop. Although the cotton from this crop appeared to be excellent as far as the eye could detect and the classers were concerned, the cotton gave low strength in many cases when spun into yarns and cords. In order to attempt to find the cause of these complaints in reference to the 1937 crop year, commonly referred to as an "off-year" as also was the case with the 1931 crop, samples of two of the varieties grown at 11 locations across the Cotton Belt during this season were spun into yarn

and tested. For purposes of control, samples of the same two varieties grown at the same locations for 1936 were tested. The results showed that the yarn from the 1937 crop was on the average 8.1 percent weaker than that in 1936, and that the longer of the two varieties was 9.6 percent weaker in yarn strength, as compared with 7.0 percent weaker in yarn strength for the shorter variety. At one location the two varieties were 25 and 36 percent weaker, respectively, in 1937 than in 1936. On the other hand, at 4 of the locations one or both of the varieties produced stronger yarn in 1937 than in 1936.

Certain Cotton Spinning Studies and Results

In addition to providing the means for evaluating the fiber properties in terms of spinning behavior and yarn and fabric properties, the spinning studies have provided valuable information along various other lines. Some of these have to do with a better evaluation of the influences of the spinning process itself on the precision of the results. Others have to do with a better understanding of some of the immediate problems in the cotton industry whose importance has not been thoroughly understood or determined.

One of the first and foremost benefits of spinning studies, as just described, is the provision of a basis or bench mark for the strength of yarn that should be expected from cottons of a given staple length. This has resulted from an experiment referred to in the previous section, which, however, is still being extended. Considerable data are now available so that any unusual strength of a yarn of a given count may be immediately recognized and the approximate extent from the average or so-called normal can be easily and quickly determined. The cause for either superior or inferior strength, as compared with the standard, may easily be sought by reference to measured fiber properties, and if any of these are outstanding, a lead is at once provided for a possible explanation.

For some purposes it is essential that measurement of strength of yarn be made on single strands of yarn. Because of the rather high variability of yarn strength and in view of the time-consuming nature of the single-strand yarn test, it has been impractical in many cases in the past to make such tests even though the results would have possessed considerable value. For some time there has been available an automatic testing machine known as the Moscrop tester for determining the strength of single strands of cotton yarn, but the usefulness of this machine has been quite limited because of the difficulty of analyzing the results. Recently we have developed in our laboratories a quick, accurate, and altogether practical method of analyzing the data obtained through the use of this automatic machine that now permits us to make much more adequate measurements of yarn quality than heretofore. There are indications, moreover, that the machine is now coming into much more widespread use in this country as a result of this development.

Along with the development of a bench mark for yarn strength, a great deal of improvement has been introduced in the spinning process itself so that much smaller samples of cotton may be spun than were required formerly and are generally considered necessary in commercial mills. Whereas, one or

several bales at least are required in most mills, it has been found possible to carry out a complete laboratory spinning test, providing information on the quantity of waste, smoothness of yarn, etc., on only 40 pounds of cotton lint.

In cases where it is not necessary to determine the amount of waste carefully, and where the main interest is in the strength of yarn, adequate data may be obtained from as little as 5 pounds or even 2 pounds of cotton lint. This achievement in spinning methodology is of importance to technologists studying cotton utilization problems when only small samples are available, or when the time, effort, and expense would not be justified in using larger or bulk lots of cotton. The standardized and tested short-cut spinning method, moreover, is of real importance to cotton breeders who cannot produce large quantities of lint from any particular strain during the first 1 or 2 years, and it obviates the great amount of time, work, and expense that would otherwise be required on the part of breeders in multiplying it extensively over a period of 5 or 6 years.

In the same way that bench marks have been obtained for cotton yarn strength, helpful bench marks also have been obtained for the amount and proportion of different types of waste that may be expected from cottons of a given grade designation. This information has been obtained from several hundred cottons tested from time to time in the cooperative spinning laboratories of this Service. Thus, the amount of waste that is furnished by a given sample of cotton may be readily compared with the basis, and the degree to which it compares with or departs from the average or so-called normal for the grade can be quickly and easily determined. This information, too, is of interest to breeders because certain varieties of cotton, by their growth habits, influence the amount of waste differently from other varieties.

A short time ago it was found possible to establish standards for yarn appearance. These standards consist of 20 full-size photographs of yarns representing different count ranges and different degrees of evenness, cleanliness, and smoothness. These standards have received much favorable comment from manufacturers and others and they have been adopted as standards by the American Society for Testing Materials.

Samples of yarn being spun in our laboratories are now easily compared on a basis of these standards and a means is thus provided for grading this rather important element of yarn quality. The standards are applicable to and of interest for many purposes. For example, through this development, we recently have discovered that different varieties of cotton behave quite differently with respect to the appearance of the yarns that are spun from them. In other words, it is becoming increasingly apparent to us that yarn appearance is more a function of variety than we heretofore have thought or even suspected.

Spinning and fiber studies of different varieties and strains of cotton have brought to light several facts that undoubtedly possess considerable significance in determining the general quality level of cotton produced in different regions of this country. For example, it has been found that the

varieties producing the highest yields of cotton of good quality according to our grade and staple standards do not always produce fiber of the highest spinning value. All of the factors that contribute to this condition are not yet fully understood. However, the information that is available shows the fundamental importance of knowing the spinning value as well as the yield value of a variety of cotton before large scale plantings in a new locality are undertaken. In a program of standardization of production and cotton quality improvement, it is clear that in a community of growers wishing to build a reputation for producing cotton of high quality, selection of the seed to be planted should be based not alone on yield but on the results of adequate spinning tests carefully conducted under controlled conditions.

Among other things, the relationship of certain ginning processes upon spinning have been studied. Thus, for cottons of about 1-1/4 inches staple length, it has been found that saw-ginning gives a lint of better spinning quality than does roller-ginning. Other ginning factors that have been studied are moisture content of the seed cotton, influence of seed-roll density, number of saws, number, size, and shape of saw teeth, speed of saws, and type and number of cleaners. This type of information is of much importance since a great deal of controversy has arisen during recent years as to the importance of some of these factors.

Another problem that is being studied and on which some preliminary information has been obtained is that of the importance of ginning preparation. Results so far seem to indicate that far too much importance has been attached to preparation. Final conclusions, however, must be withheld until studies are completed.

Studies have shown that methods that produce cottons most pleasing to the eye are not necessarily best from the standpoint of spinning quality. One such finding was that seed cotton, dried in the sun before ginning, had materially lower spinning quality than portions of the same seed cotton dried artificially in a drier or under cover in a drying shed. Sun drying gave a lint with smoother preparation and beautiful appearance. Nevertheless, when spun, it yielded a greater amount of spinning waste and yarn of noticeably lower strength. Artificial drying does not give any appreciable loss of strength providing it is properly carried out.

Still another matter that has received some attention recently is that of so-called "air cutting." This in reality is not air-cutting at all, but the result of shearing due to uneven density in the bale at the time of compressing. There has been a popular belief that "air cutting" which is noticeable in many bales of cotton, particularly those compressed to a high density, results in inferior spinning quality. Tests that we have conducted have not confirmed this belief and in fact even some of the most badly cut bales have shown no serious reduction in spinning quality.

Tests are now under way to determine the influences of the different methods of packaging and different degrees of compression upon the spinning quality of cotton. There has been considerable belief in the past that a high degree of compression, such as results from the packaging of cotton in

so-called high-density bales, causes material reduction in spinning quality. The findings from the tests completed to date for the past season indicate that this belief may be erroneous. Final conclusions in this connection, however, should await the completion of the tests now in progress or proposed.

SELECTED PUBLICATIONS

A considerable part of the material presented in this paper is based on unpublished data and on presentations published in various Departmental and outside publications that were prepared for diverse purposes. For the assistance of those who may wish to follow up certain details, however, the publications mentioned and the more pertinent ones referred to by implication are listed as follows:

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SUMMARY

In this presentation, emphasis is given to the great range of values for various cotton fiber properties which have been found in connection with the cotton quality and standardization researches of the Agricultural Marketing Service, and to the significance of cotton fiber properties and their variabilities with respect to cotton utilization as well as to standardization, marketing, breeding, production, and improvement programs. A number of background considerations preface the discussion, features of which are not realized by the average layman nor even by every student of cotton. The importance of these matters to cotton utilization and utilization studies, as well as to other related practical cotton problems and associated studies is such that they properly cannot be overlooked nor underestimated.

The greater part of the paper deals with various accomplishments by the several fiber and spinning laboratories of the Agricultural Marketing Service that are of interest, directly or indirectly, to cotton utilization and utilization studies. The achievements reported have to do with the development of instruments and methodology for measuring staple length, grade, and character factors; with service to the grade and staple standards; with the evaluation of the importance of cotton fiber properties in terms of spinning quality or utility; and with certain cotton spinning studies and results in reference to various practical cotton problems of importance to cotton breeding and production; ginning and packaging; standardization and marketing.

The comparisons that are made reveal the relatively great variability that occurs in American cotton quality, not only from season to season but from place to place within a given season. More important, perhaps, they show how inaccurate and unfair it is to attempt to speak of cotton quality from the standpoint of the crop as a whole, or even of any major section of it, on the basis of data from only a comparatively few tests and locations of growth. It is evident that a careful statistical study of the influence of climatic, soil, and other conditions on fiber and yarn properties for the entire Regional Variety Series is needed and such a study will be undertaken as soon as data from all of the varieties, locations, and years have been assembled.

In the light of the many questions, implications and suggestions which the reported findings and comparisons afford, it is evident that the field of

scientific study of cotton quality is almost limitless and only just begun. There are many complex problems and most of them have many fringes and relationships. For the most part, only the fringes have been explored to date. However, studying cotton quality from the scientific standpoint yields much that has immediate and more distant practical value.

Comparative spinning and fiber tests of different varieties and growth conditions furnish the best known method by which answers can be supplied to many questions of immediate practical importance to cotton farmers and the cotton industry. These tests also furnish facts by which, and only by which, the United States can ascertain how to deliver consistently to world markets and mills better quality cotton of known characteristics; superior varieties that will more effectively meet ordinary and special use requirements; and American cotton that will possess the greatest possible strength, beauty and appeal to spinners and other manufacturers.

Cotton fiber and spinning data of this type, moreover, should be of direct interest and importance in many ways to the utilization of American cotton and to studies on cotton utilization. However, along with the great effort that is being made to create new outlets and channels of utilization for American cotton, and during the hustle and bustle to develop new and extended uses for our cotton, the fact should never be lost sight of that we, at the same time, also must work equally as hard to hold the "old outlets and channels" of utilization which American cotton has, without question, enjoyed for so many years.

But, to do all this requires that our knowledge with respect to cotton quality and fiber properties must reach the fundamentals and must be translated into everyday practices throughout the cotton enterprise. That is, we must have the exercise of intelligent and concerted action in all operations, beginning with the breeding and growing phases and extending through the activities of ginning, packaging, and marketing to those of manufacturing and finishing. What knowledge we have had in the past is not good enough! And what we have done heretofore is insufficient.